INCREASING EVAPORATION OF A PROCESS WATER POND

TECHNICAL FIELD

[01] This invention relates generally to production facilities and processes. More particularly, the invention concerns methods for controlling the level of a process water pond associated with a production facility, such as a chemical production plant.

BACKGROUND

[02] Water provides various important functions at production plants, and in particular, at chemical production plants. For chemical production plants, water often plays important roles in chemical processes themselves, such as being a reagent for the process, a transport agent, and/or a by-product of a process. Because many chemical reactions require a controlled heating environment and/or are exothermic in nature, water can play a role in managing heat, such as by cooling the reaction or heated environment or by pre-heating reagents. Many of these uses for water can be met with impure water, such as water from a production process that includes various solutes and suspended particulate. As such, process water ponds are maintained at production facilities to meet these needs.

[03] Process water ponds for conventional production plants are designed to have an adequate capacity for expected production demands during standard rainfall cycles and seasonal conditions. During drought conditions, process water usage may be supplemented with freshwater as needed. However, during other environmental cycles such as periods of

excessive rainfall, process water may need to be released to the environment as ponds reach their capacity. Due to the pH of the process water, solutes and/or particulate matter in the process water, or other undesirable water conditions, such water may need to be filtered, neutralized, or otherwise processed prior to release to the environment. This processing is expensive, time-consuming, and often impractical. Accordingly, a need exists for improved methods for controlling the water level of process water ponds.

[04] Solutes and/or particulate matter in process water often have commercial value. As such, process water can be recycled into production processes to capture the desirable substances. A conventional method for recycling process water includes simply reusing process water as an input to production processes. This method is generally inefficient, and may be even more inefficient during years of excessive rainfall, which causes the desirable substances to be more dilute in the process water pond. Accordingly, a need exists for improved methods for capturing desirable substances from process water.

[05] Fig. 1 shows, by way of example, a conventional chemical processing facility 10. Chemical processing facility 10 includes a chemical processing plant 12, a process water pond 14 and a solid by-product stack 16. In this example, plant 12 produces chemical X according to the following exothermic reaction: $AX + B + \text{water} \rightarrow AB(\text{solid}) + X(\text{aq.}) + \text{heat}$. This reaction primarily occurs in a reactor, after which solid by-product AB is filtered from the output mixture, and aqueous chemical X is subsequently concentrated. As a result of concentrating chemical X, process water is available that contains small

amounts of chemical X and process impurities. The process water may be used immediately or pumped to process water pond 14 for storage until needed.

[06] The process water is used in plant 12 or throughout facility 10 for various purposes. For example, it acts as a transport mechanism for moving solid by-product AB to by-product stack 16, such as by suspending solid by-product AB in process water and pumping the mixture to stack 16. Process water may also be used to cool the exothermic reaction used to produce chemical X. For example, ambient temperature process water from pond 14 may be cycled through evaporators, flash coolers and the like to assist cooling processes. These uses of process water are generally kept in equilibrium with the production of process water as a by-product of making chemical X and with environmental losses.

[07] Process water pond 14 is sized to maintain sufficient capacity for expected production demands during normal rainfall cycles and standard seasonal variations. If it is too large, the water level may often be too low for cycling usable process water for production needs. If it is too small, it's capacity may often be exceeded. As such, process water ponds are typically sized for expected demand and for standard seasonal variations. Thus, the water level of process water pond 14 varies between high and low levels in response to production demands and environmental conditions. However, conventional process water ponds fail to provide sufficient capacity for extreme weather cycles, such as wetter than average cycles caused by an El Nino pattern or tropical storms.

[08] For example, during normal season variations, evaporative heat losses from pond 14 may be greatly reduced during winter months due to lower temperatures. In addition, these same months may ordinarily experience increased rainfall. As such, process water pond 14 may have sufficient capacity to store the expected additional rainfall and lower pan evaporation rate. However, if the rainfall is excessive and/or the temperatures are excessively cool, the capacity of process water pond 14 may be quickly exceeded. This may be particularly true depending on the size of the watershed 28 that contributes run-off rainwater to pond 14. Conventional production facilities 10 lack the ability to control the level of process water pond 14 during these periods of abnormal environmental conditions. As such, conventional facilities 10 are often forced to release process water to the environment, which incurs expenses such as water treatment costs and water transport costs, or even worse, results in uncontrolled release of process water.

[09] Stagnant process water ponds often remain after a production facility ceases operation or begins to use a new process water pond. These stagnant process water ponds often constitute an environmental hazard due to substances in the process water. If left alone, these ponds can exceed their capacity and release process water to the environment. In order to clean up these stagnant ponds, the process water is treated and drained, which is an expensive process. Accordingly, a need exists for an improved method of cleaning-up stagnant process water ponds.

[10] As further shown in Fig. 1, to meet demand for electricity and to make use of waste heat, many conventional production facilities 10 include a power plant 18. Power plant 18 includes a heat recovery steam turbine 20, a condenser 22, and a cooling tower 24. Steam turbine 20 can recover heat from various sources, such as gas turbine exhaust gases, furnace exhaust gases, and/or heat from an exothermic reaction, such as the reaction to produce chemical X. Feedwater pumped to production plant 12 absorbs waste heat via boiler 26, changes to steam, and becomes superheated. The superheated steam drives steam turbine 20 to produce electricity. Upon exhaust from steam turbine 20, the steam is cooled in condenser 22 where it changes phases from steam to water. A coolant absorbs heat from the steam as it passes through condenser 22 and subsequently circulates through cooling tower 24 where it releases heat. The released heat is a loss to the overall production process, as it is simply transferred to the environment and accomplishes no work. Accordingly, a need exists for a method and system that makes use of potential energy related to heat lost from condensers related to power production, such as condenser 22.

[11] In conventional systems, the coolant cycled between cooling towers 24 and condenser 22 is substantially pure, and is maintained in a closed loop. For example, substantially pure water is pumped in a closed loop between condenser 22 and cooling tower 24. Such a pure coolant is used to prevent fouling of condenser 22 or other portions of the cooling loop. Fouling of condenser 22 can cause expensive delays and increase maintenance costs. Such fouling is often caused by scaling and corrosion of the inside surfaces of

condenser tubes, which may be caused by impurities in the coolant that precipitate out of the coolant. Fouling may also occur due to corrosive effects of the coolant on condenser 22 and associated piping if the coolant has a high or low pH level. Thus, a closed loop system is used in conventional systems to prevent the introduction of impurities and associated fouling.

[12] As discussed above and shown by way of example, there is a need for improved systems and methods for controlling the level of process water ponds. Further, a need exists for improved methods of capturing desirable substances from process water. Additionally, a need exists for a method and system that makes use of heat lost to the environment from power plant cooling operations.

SUMMARY

[13] In order to overcome the above-described problems and other problems that will become apparent when reading this specification, aspects of the present invention provide a method for controlling the level of a process water pond. According to one aspect of the invention, a method for controlling the level of a process water pond includes increasing the evaporation rate of the process water pond through the addition of heat from a power plant. According to another aspect, the method includes pumping process water through a condenser of the power plant. According to a further aspect, the method includes pumping substantially pure feedwater between a condenser of the power plant and a heat exchanger in thermal communication with the process water pond. According to yet

another aspect, the method includes selectively pumping feedwater between a cooling tower and a condenser of the power plant, and pumping process water between the process water pond and the condenser, depending on environmental conditions.

[14] Aspects of the present invention further provide a method for increasing recovery of substances contained in process water ponds by increasing the evaporation rate of the process water pond and using the process water in a current production process. Aspects additionally provide a method for reducing the volume of a stagnant process water pond by increasing the evaporation rate of the stagnant process water pond via the addition of waste heat from a power plant. Other features and advantages of various aspects of the invention will become apparent with reference to the following detailed description and figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[15] The invention will be described in detail in the following description of preferred embodiments with reference to the following figures wherein:

[16] Fig. 1 shows a conventional production facility;

[17] Fig. 2 shows a production facility according to an embodiment of the invention;

[18] Fig. 3 shows a wet-process production method for manufacturing phosphoric acid in the production facility of Fig. 2 according to the embodiment of Fig. 2;

[19] Fig. 4 illustrates steps involved with a method for increasing the evaporation rate of the process water pond according to the embodiment of Fig. 2;

[20] Fig. 5 illustrates steps involved with a method for selectively increasing the evaporation rate of the process water pond according to the embodiment of Fig. 2;

[21] Fig. 6 shows a production facility according to the another embodiment of the invention;

[22] Fig. 7 illustrates steps involved with a method for increasing the evaporation rate of a process water pond according to the embodiment of Fig. 6;

[23] Fig. 8 shows a production facility according to a further embodiment of the invention;

[24] Fig. 9 illustrates steps involved with a method for capturing desirable substances from process water according to the embodiment of Fig. 8; and

[25] Fig. 10 illustrates steps involved with a method for increasing the evaporation rate of a stagnant process water pond according to the embodiment of Fig. 8.

DETAILED DESCRIPTION OF THE FIGURES

[26] The various aspects of the invention may be embodied in various forms. The following description of the figures shows by way of illustration various embodiments in which aspects of the invention may be practiced. It is to be understood that other embodiments may be utilized and structural and functional modifications may be made without departing from the scope of the present invention. Referring now to Figs. 2-3, a phosphoric acid production facility 110 is shown according to an embodiment of the invention, which includes a process water pond containing process water in thermal communication with a steam turbine. Although a phosphoric acid production facility is shown and described as an illustration, aspects of the invention are applicable to a wide variety of manufacturing and production facilities and processes. Further, the term process water as used herein generally means water used in processing and/or manufacturing industries, such as chemical processing industries and food processing industries, which includes by-products, residues, particulate, precipitate, or other impurities from a commercial process. As such, a process water pond generally means a storage medium for process water. In addition, the term thermal communication as used herein generally refers to a heat transfer relationship between two or more entities, which may include conduction, convection, and/or radiation heat transfer mechanisms through a direct or indirect relationship.

[27] Suppose as an example that phosphoric acid production facility 110 produces phosphoric acid for use in producing fertilizer. As shown, facility 110 includes a phosphate processing plant 112, a sulfuric acid plant 113, a process water pond 114 and a gypsum

stack 116. Suppose plant 112 produces phosphoric acid via a wet-process by reacting sulfuric acid from sulfuric acid plant 113 with phosphate rock. The phosphate rock may be obtained from mining and recovery operations (not shown) that may be co-located with the phosphoric acid production facility 110.

[28] The sulfuric acid plant 113 may produce sulfuric acid using various processes. These processes generally include burning sulfur to obtain sulfur dioxide. Through catalytic oxidation, the sulfur dioxide is changed to sulfur trioxide (SO_3), which is combined with water to form sulfuric acid (H_2SO_4). Each of these reactions is exothermic. The heat from one reaction is often used for other reactions. For example, heat generated from the step of burning sulfur provides input heat for the step of catalytic oxidation. However, a net amount of waste heat is produced. This waste heat is captured in superheated steam for use with power plant 118 via boiler 126, which may be a boiler used in conjunction with the sulfur-burning operation. The waste heat may also be captured into power plant steam via a heat exchanger (not shown) or via other methods.

[29] As shown in Fig. 3, the phosphate processing plant 112 may produce phosphoric acid using various methods. Suppose a wet-process production method 130 for phosphoric acid is used, which includes the following equation representing the net effect of two stages: $Ca_{10}F_2(PO_4)_6 + 10H_2SO_4 + 10nH_2O \rightarrow 10CaSO_4{\cdot}nH_2O + 6H_3PO_4 + 2HF$, where n=0, ½, or 2 depending on the hydrate form in which the calcium sulfate ($10CaSO_4$) crystallizes. Pure fluorapatite ($Ca_{10}F_2(PO_4)_6$) represents phosphate rock 132 in the above

equation. Phosphoric acid 134 reacts with the fluorapatite of the phosphate rock 132 to form monocalcium phosphate ($CaPO_4$) in the first stage, and monocalcium phosphate reacts with sulfuric acid (H_2SO_4) 136 in the second stage to form phosphoric acid (H_3PO_4) 134 and calcium sulfate ($CaSO_4$) 138. Note that the reaction overall forms aqueous phosphoric acid (H_3PO_4) 134, solid calcium sulfate ($CaSO_4$) 138, which is the primary component of gypsum, and aqueous hydrogen fluoride (HF). The resultant also includes impurities, such as sodium, potassium, magnesium, chloride, fluoride, and ammonia nitrogen. The HF reacts with silica and some of these impurities to form fluosilicates and other compounds. Side reactions also form numerous other impurities.

[30] Fig. 3 generally shows process steps of a sample wet process reaction 130 for forming phosphoric acid 134 from fluorapatite 132 and sulfuric acid 136. Initially, phosphate rock 132, which has preferably been ground into small particles, is mixed with water 140, weak phosphoric acid 134, and sulfuric acid 136 in a reactor 142. Because the reaction is exothermic, one or more flash coolers 144 may be used to cool the resultant materials along with a corresponding condenser 146. This allows steam used with the corresponding flash cooler 144 to condensate and be reused. One or more scrubbers 148 may be used to reduce the amount of impurities escaping to the atmosphere. The resultant from this reaction, which may occur in one or more reactor tanks, is subsequently filtered in hydrate filter 135 to remove crystallized calcium sulfate 138 (hydrate) from the slurry. The hydrate or gypsum 138 is then transported to gypsum stack 116 and the residual solution is moved to a concentrator 144.

[31] Concentrator 144 generally separates concentrated phosphoric acid 146, which contains about 26-54% P_2O_5 depending on the processes used, from the rest of the solution. The remaining solution is process water 148, which may include about 0.50% to about 2.0% P_2O_5 depending on processes used, and more particularly about 1.5% P_2O_5. Process water 148 may further include other residual substances, such as calcium sulfate ($CaSO_4$), hydrogen fluoride (HF), sodium, potassium, magnesium, chloride, fluoride, ammonia nitrogen, silica, fluosilicates and other compounds. Process water 148 that is not needed immediately may be transported to process pond 114 for future uses.

[32] Process water 148 may be used immediately in plant 112 or throughout facility 110 for various purposes. For example, it can act as a transport mechanism for moving gypsum 138 to gypsum stack 116 by suspending gypsum 138 in process water and pumping the mixture to stack 116. As a result, an aboveground process water pond 117 develops from the transport water as gypsum stack 116 grows. Process water may also be used with flash cooler 144 and condenser 146 to cool the exothermic reaction of reactor 142. It may further be used with venturi scrubber 148 to remove impurities from exhaust gases, such as fluoride. In addition, process water 148 is preferably used as input water 140 to reactor 142. As such, phosphoric acid contained in process water 148 is captured and used as part of the processing of phosphate rock 132. Process water 148 may further be used at the sulfuric acid processing plant 113 or other plants within facility 110. In general, these uses of process water are generally kept in equilibrium or at a slight net

loss with respect to the production of process water from process 130 and evaporative losses from process water pond 114.

[33] Process water pond 114 is sized to maintain sufficient capacity for expected production demands during normal rainfall cycles and normal seasonal variations. Although shown as a single pond 114, multiple process water ponds may exist at a production facility 110. Process water pond 114 may support process water needs for a number of different production plants at a production facility 110 and may include impurities from these other processes. For example, if a fertilizer plant (not shown) is a part of facility 110, process water may include ammonia. Further, its size depends on the processes it supports. If it is too large, the water level may often be too low for cycling usable process water for production needs. If it is too small, it's capacity may often be exceeded. As such, process water pond 114 is sized for expected demand and for average seasonal variations. Thus, the water level of process water pond 114 varies between high and low levels in response to production demands and environmental conditions.

[34] Suppose as an example that process water pond 114 covers an area of about 300 acres and varies in depth at 70% capacity between 5 to 8 feet, with an average depth of 7 feet at 70% capacity and a maximum average depth of 10 feet at 100% capacity. As such, process water pond 114 on average holds about 680 million gallons of water at a normal 70% capacity. Suppose also that watershed 128, which drains into process water pond 114, has an area of about 1,000 acres. As such, for every inch of rain that falls on

watershed 128 and process water pond 114, about 35 million gallons of rainwater enters process water pond 114. Suppose further that process water pond 114 and watershed 128 together receive 20" or 0.7 billion gallons of water from rainfall each year, and that pan evaporation based on standard seasonal conditions results in a loss of about 58" or 0.5 billion gallons of water per year from process water pond 114. Suppose also that approximately 0.5 billion gallons of water per year are generated through operation of the plants at production facility 110, such as via wet-process production method 130, and that about 0.8 billion gallons are used or evaporated via use of process water in the plants of production facility 110.

[35] In such a scenario, process water pond 114 realizes a net loss of about 0.1 billion gallons per year or about 275,000 gallons extra evaporation per day. During standard seasonal conditions and rainfall, this deficit can be accommodated through additional use of freshwater at the plants of facility 110. During drought conditions or years of cooler temperatures and/or less sun exposure, even more freshwater may be used as necessary. However, if the rainfall is excessive and/or the temperatures are excessively cool, the capacity of process water pond 114 may be quickly exceeded. For example, suppose that during an El Nino year that process water pond 114 and watershed 128 experience an additional 9 inches of rainfall in a single year. Due to the runoff from watershed 128, process water pond 114 experiences a net increase of close to 39 inches of rainwater, which exceeds it's capacity by about 10 million gallons or 3 inches of pond depth.

[36] Without a means for increasing evaporation of process water pond 114, it may be necessary to treat and discharge the excess process water volume. This can be expensive and environmentally undesirable due to the substances in the process water. For example, due to phosphoric acid in the water, as well as potentially sulfuric and fluosilicic acids, the pH may be about 1 to 3. In order to neutralize the water, lime is added to increase the pH to approximately 4.5 and solids formed are removed. Lime is further added to increase the pH to approximately 11 and formed solids are again removed. If necessary, the water can be air stripped to remove ammonia and, as needed, acid can be added to lower the pH to approximately 6.5. Further treatment may be required to remove dissolved solids. These processes can be time consuming and expensive. It may also not be possible to successfully remove all impurities to a safe level, which can be harmful to the environment.

[37] Increasing the evaporation rate of process water pond 114 can reduce, if not eliminate, the need to lime or otherwise treat process water during such abnormal season conditions. As shown in Fig. 2, the evaporation rate of process water pond 114 can be increased by adding waste heat from power plant 118 to process water pond 114. For example, suppose approximately 150 MBtu/hour of thermal energy is transferred to process water pond 114 from power plant 118. This relates to an increase in the evaporation rate of 450,000 gallons/day, or the equivalent of an extra 5 inches capacity in process water pond 114. The thermal energy transferred can include waste heat from a steam turbine 121 within power plant 118.

[38] As shown in Fig. 2, steam turbine 121 includes a steam turbine 120, a condenser 122, and a cooling tower 124. As an example, steam turbine 121 represents an axial flow, single stage, condensing steam turbine that drives a generator, such as a 20 MW electric generator (not shown). However, steam turbine 121 may represent any number of steam turbines, such as any of the following types of turbines: noncondensing, automatic extraction, mixed pressure, regenerative extractions, reheat, single casing, tandem compound, cross-compound, two-flow, four-flow, six-flow, impulse, reaction, radial flow, tangential flow, multistage, etc. As such, thermal energy transferred from steam turbine 121 to process water pond 114 may be associated with waste heat from various sources and/or stages related to steam turbine 121. In the present example, waste heat is recovered from condenser 122 as low-pressure exhaust steam that condenses back into feedwater.

[39] Feedwater for steam turbine 121 may be changed into superheated steam by absorbing waste heat from production processes. By capturing waste heat from these processes, electricity demand for production facility 110 may be met, and excess electricity may often be produced and sold to utility companies. As an example, waste heat from a sulfur-burning operation of boiler 126 in the sulfuric acid processing plant 113 may be used to heat steam turbine feedwater into superheated steam 119. This may be accomplished via one or more evaporators and/or heat exchangers (not shown). Suppose as an example that superheated steam 119 is heated to a temperature of approximately 875°F at a pressure of about 875 lb/in^2 absolute. As input to steam turbine 120, the

superheated steam 119 drives the steam turbine, which in turn drives a generator (not shown) to produce electricity. The pressure of steam 119 drops approximately 872 lb/in^2 absolute as it moves through steam turbine 120 to a pressure of about 3 lb/in^2 absolute when it exhausts the turbine. The low-pressure exhaust steam of turbine 120 enters condenser 122, where it changes phases to feedwater at approximately 3 lb/in^2 absolute. As such, thermal energy equal to the latent heat of vaporization of the feedwater at the condensing pressure is released as waste heat.

[40] Suppose that the steam is pumped through condenser 122 at a rate sufficient to produce about 320 gallons/min of condensate, or about 2700 lb/min. Because the heat of vaporization of water is about 965 Btu/lb, approximately 2.6 MBtu/min or 155 MBtu/hr is released. This waste heat may be removed to the environment by cycling a coolant (not shown) between cooling tower 124 and condenser 122. The coolant (not shown) absorbs the waste heat while passing through condenser 122 and expels the waste heat as it passes through cooling tower 124. Cooling tower 124 sprays freshwater onto tubing (not shown) within cooling tower 124 through which the coolant (not shown) is pumped. Evaporation of the freshwater removes heat from the coolant and thereby transfers the waste heat to the atmosphere. The released waste heat is a loss to the overall production process, as it accomplishes no work. Further, such a cooling process using cooling tower 122 wastes freshwater, which can be expensive.

[41] As shown in Fig. 2, a process water cooling system 150 may exist as a replacement for or in parallel with cooling tower 122 and its associated cooling system (not shown). The process water cooling system includes a pump 152, inlet piping 154, condenser 122, and outlet piping 156. Pump 152 draws process water from process water pond 114 into piping 154 for circulating through condenser 122 and returning via outlet piping 156 to process water pond 114. Pump 152 can be one of a variety of different pump types sufficient to circulate water to and from condenser 122. Suppose as an example that pump 152 is a vertical submersible turbine pump that can pump approximately 20,000 gallons/min at about 80 feet of head when the inlet is submersed about 5 feet under the surface of process water pond 114.

[42] Suppose also that inlet and outlet piping 154 and 156 are made from 30 inch stainless steel pipe. Although a variety of piping materials may be used, stainless steel pipe may be preferable due to the corrosive properties of process water. For example, the following forms of stainless steel may be appropriate for process water usage: 316L, Hastalloy C, Hastally G, Alloy 20, 904L, and Zirconium. In the present phosphoric acid scenario, 316L is preferable due to its corrosion and fouling resistance with respect to the silica fluoride and phosphoric acid content of such process water, as well as its lower cost in comparison with other grades. Other corrosion resistant and fouling resistant materials may also be used, such as high-density polyethylene piping or other plastic materials.

[43] According to the present embodiment, condenser 122 may be a surface condenser made at least in part from stainless steel such as one of the grades discussed above with respect to piping 154 and 156. Preferably, condenser tubing 123 through which process water is circulated is made from a corrosion/fouling resistant grade of stainless steel as discussed above, and more preferably, process water tubing 123 is made from 316L stainless steel. Other corrosion resistant or fouling resistant materials may also be used, such as rubber lined carbon steel tubing.

[44] Condenser 122 is generally a heat exchanger that allows a coolant, such as process water, to be circulated through condenser tubing 123, which is in contact with low-pressure exhaust steam from steam turbine. In conventional systems, the coolant is typically substantially pure to prevent fouling of condenser tubing. Such fouling is often caused by scaling and corrosion of the inside surfaces of condenser tubes, which may be caused by impurities in the coolant that precipitate out of the coolant. Fouling may also occur due to corrosive effects of the coolant on condenser 22 and associated piping if the coolant has a high or low pH level. This may be particularly true when using process water as the coolant with a conventional condenser, as process water may have a pH level as low as about 1. Further, process water may include various impurities that can precipitate out of the process water to foul a conventional condenser. Through the use of a corrosion resistant material, such as stainless steel, for condenser tubing 123, fouling of condenser 122 may be avoided when using process water as the coolant. Further, a high

coolant flow rate may also reduce or prevent fouling of condenser tubing 123 by reducing the amount of precipitate and scale build-up.

[45] According to the present example, process water from process water pond 114 is pumped by pump 152 through condenser 122 at a rate of about 20,000 g.p.m. As such, process water moves about 2.3 ft./sec. through piping 154 and 156. However, the process water circulates through smaller tubes 123 within condenser 122 at a higher rate. For example, process water may circulate through a number of parallel ¾" tube banks 123 within condenser 122 at a rate of about 10 ft./sec. At this higher velocity, fouling is reduced in condenser 122. In order to ensure fouling is kept at a low rate, one or more coupons (not shown) of tubing material (e.g., stainless steel) may be placed in the flow of process water through condenser 122. These coupons may be removed periodically to evaluate corrosion, scaling, etc.

[46] As steam condenses while passing through condenser 122, it gives up approximately 2.6 MBtu/min or 155 MBtu/hr of thermal energy. The process water absorbs this energy as it passes through condenser 122 and experiences a corresponding increase in temperature. For example, process water may enter condenser 122 at a temperature of about 90°F and exit at about 105°F. Process water may also experience a pressure loss of about 35 feet of head as it circulates through condenser 122. Upon exiting condenser 122, process water is transported via outlet piping 156 back to process pond 114, where it mixes with cooler process water in pond 114. Accounting for heat losses as it travels back to process pond

114, heated process water provides about 130 MBtu/hour of thermal energy to process pond 114. This results in an increased evaporation rate of about 250 gallons/minute or over 10 million gallons/month.

[47] Referring now to Fig. 4, steps involved with a method 170 for increasing the evaporation rate of process water pond 114 are shown. Method 170 includes the steps of drawing 172 process water from process water pond 114 into inlet pipe 154, and pumping 174 the process water through inlet pipe 154 to condenser 122 in thermal communication with steam from turbine 120. The method further includes circulating 176 the process water through condenser 122 to absorb thermal energy from the turbine steam, and pumping 178 the process water from condenser 122 through outlet pipe 156 to process water pond 114. As such, heated process water is returned to process water pond 114.

[48] Method 170 may be used as an exclusive method for removing heat from turbine steam via condenser 122. However, method 170 is preferably used along with cooling tower 124 to remove heat from turbine steam. For example, process water cooling system 150 may be selectively used as needed to increase the evaporation rate of process water pond 114. For instance, during drought conditions, cooling tower 124 may be used to remove heat from turbine steam. During above average rainfall conditions, process water cooling system 150 may be used.

[49] Switching between these options for removing heat from turbine steam via condenser 122 provides flexibility for controlling the evaporation rate, and therefore the volume water level, of process water pond 114. Switching between these options may be done for various purposes, such as to accommodate changes in production rates or environmental conditions. It may further be done substantially automatically based on predetermined levels of process water pond 114. For instance, when the pond reaches a certain high volume level, heat may be transferred from turbine steam to process water pond 114 via process water cooling system 150. When pond 114 reaches a certain low volume level, heat may be transferred from turbine steam via cooling tower 124. Such switching may be accomplished by various means, such as by changing piping configurations when needed. It may further be accomplished by providing switchable valving, such as three-way valves (not shown), to selectively switch inlet and outlet flows to condenser 122 as desired between piping for cooling tower 124 and process water cooling system 150.

[50] Referring now to Fig. 5, steps involved with a method 180 for selectively increasing the evaporation rate of process water pond 114 by switching between these options is shown. Method 180 includes the step of transferring 182 thermal energy from power plant 118 to process water pond 114 on condition the process water pond reaches a predetermined high level. Method 180 further includes the step of transferring 184 thermal energy from power plant 118 to cooling tower 124 on condition the process water pond reaches a predetermined low level.

[51] Increasing the evaporation rate of process water pond 114 provides a number of advantages. As discussed above, increasing the evaporation rate of process water pond 114 can allow process water pond 114 to accommodate additional rainfall and/or decreased pan evaporation related to abnormal environmental conditions. This can reduce and even eliminate the need to lime or otherwise treat excess process water. Further, cycling process water through condenser 122 using process water cooling system 150 rather than cooling tower 124 reduces freshwater usage, due to reducing freshwater usage associated with cooling tower 124.

[52] In addition, increasing the evaporation rate of process water pond 114 has the net effect of increasing the concentration of phosphoric acid in the process water. As shown in Fig. 3, when process water is recycled as input water 140 to wet-process production method 130, phosphoric acid contained in the process water is recovered. As the concentration of phosphoric acid in process water increases due to increased evaporation, more phosphoric acid may be captured by recycling the process water into wet-process production method 130.

[53] Referring now to Fig. 6, a phosphoric production facility 210 according to another embodiment of the invention is shown. Facility 210 generally includes the same aspects and preferences as facility 110 and methods 170 and 180, except as related to process water cooling system 250 and method 270 for removing heat from a steam turbine. As shown, process water cooling system 250 includes a pump 253, inlet piping 154,

condenser 122, outlet piping 156, heat exchanger 258, and coolant 259. Process water cooling system 250 generally includes the same aspects and preferences as process water cooling system 150, except as related to pump 253, heat exchanger 258, and coolant 259.

[54] As opposed to the open system of cooling system 150 shown in Fig. 2 that uses process pond water as a coolant, cooling system 250 is a closed system that recirculates coolant 259. Coolant 259 is preferably substantially pure water; although, other substances may be used, such as a water/glycol mixture. As a substantially pure substance, coolant 259 reduces the possibility of corrosion and fouling within cooling system 250, and in particular, within tubing 123 of condenser 122. Pump 253 can be one of a variety of different pump types sufficient to circulate coolant 259 throughout cooling system 250. Suppose as an example that pump 253 is a centrifugal pump that can pump coolant 259 at a rate of about 20,000 gallons/min at a pressure of about 35 p.s.i.

[55] Heat exchanger 258 can be one of a variety of different heat exchanger types sufficient to substantially transfer the heat absorbed by coolant 259 as it passes through condenser 122 to process water circulated through heat exchanger 258. For example, a fixed tubesheet or u-tube bundle heat exchanger may be used. In such a heat exchanger 258, coolant 259 circulates through one or more small-diameter tube bundles 123 that come into contact with process water. Because the process water flows through larger channels (not shown) than the coolant tube bundles 123 (e.g., the shell of a shell-and-tube heat exchanger), the chance of fouling due to impurities in process water or the pH of process water is

reduced. For instance, larger channel sizes (not shown) for the shell side of shell-and-tube heat exchanger 258 reduces the probability of compounds precipitating out of the process water. Further, any fouling of the larger channels (not shown) would be unlikely to significantly restrict or block fluid flow therethrough.

[56] The flow of process water through heat exchanger 258 can be parallel, counter flow, or a mixture thereof in relation to flow of coolant 259. On the process water side of heat exchanger 258, pump 152 draws process water from process water pond 114 and pumps it through heat exchanger 258, rather than through condenser 122 as with cooling system 150. As discussed above, heated coolant 259 circulates through heat exchanger 258 and thereby transfers thermal energy to process water pumped therethrough.

[57] Recirculating coolant 259 through system 250 may provide various advantages. As mentioned above, it reduces the possibility of fouling inside the tubing 123 of condenser 222. Further, it allows more flexibility in the operation of cooling system 250. For example, cooling system 150 shown in Fig. 2 may need to pump process water at a higher rate to reduce fouling. In addition, cooling system 150 may need to avoid allowing process water to be stagnant within condenser 122 to further reduce fouling. In contrast, the use of a substantially pure coolant 259 in cooling system 250 may avoid some of these limitations and permit more operational flexibility. In addition, cooling system 250 may reduce the amount of corrosion-resistant stainless steel components used in comparison with cooling system 150, which may reduce costs.

[58] Cooling system 250, however, is likely to be less efficient than cooling system 150, due to losses through heat exchanger 258. For instance, heat exchanger 258 may only be 75% efficient for transferring heat between coolant 259 and process water. As such, less heat is transferred to process water pond 114. Thus, the evaporation rate may be increased less in comparison with the use of cooling system 150.

[59] Referring now to Fig. 7, steps involved with a method 290 for increasing the evaporation rate of process water pond 114 are shown. Method 290 includes the steps of circulating 292 coolant 259 between condenser 122 and heat exchanger 258, and drawing 294 process water from process water pond 114 through heat exchanger 258. As such, coolant 259 absorbs heat from turbine steam via condenser 122 and transfers it to process water via heat exchanger 258. The method 290 further includes expelling 296 heated process water into process water pond 114. Thus, heated process water is returned to process water pond 114.

[60] As with method 170, method 190 may be used as an exclusive method for removing heat from turbine steam via condenser 122. However, method 190 is preferably used along with cooling tower 124 to remove heat from turbine steam. Further, as with method 180, method 190 may be used in concert with cooling tower 124 to selectively increase the evaporation rate of process water pond 114. For instance, during drought conditions, cooling tower 124 may be used to remove heat from turbine steam. During above average rainfall conditions, process water cooling system 250 may be used.

[61] Referring now to Fig. 8, a phosphoric production facility 310 according to a further embodiment of the invention is shown. Facility 310 generally includes the same aspects and preferences as facility 110 and methods 170 and 180, except as related to increasing the evaporation rate of stagnant process water ponds 117 and 307. Stagnant process water pond 117 is an above-ground pond formed from process water used to pump gypsum to gypsum stack 116. Stagnant process water pond 307 is a below-ground process water pond left over from previous production processing.

[62] Both of these stagnant process water ponds can constitute an environmental hazard due to substances in the process water. If left alone, these ponds can exceed their capacity and release process water to the environment. For example, due to watershed 309, stagnant process water pond 307 can fill at a fast rate during periods of heavy rainfall, such as during tropical storms. In the case of process water pond 117, the process water pond may need to be drained as part of an effort to close gypsum stack 116. In order to clean up these stagnant ponds, the process water is typically treated and drained, which is an expensive process. In addition, substances dissolved in and/or suspended in process water ponds 117 and 307 may have value and should therefore be captured. For example, it may be desirable to capture the phosphoric acid contained in these ponds.

[63] Increasing the evaporation rate of these ponds can reduce their volume, which reduces the possibility of inadvertent release of process water to the environment. Further, as these ponds dry up, the concentration of useful substances, such as phosphoric acid, increases.

Thus, it may desirable to recycle process water from these stagnant ponds into production processes as they dry up so that useful substances may be more easily captured.

[64] As shown in Fig. 8, process water cooling systems 350 and 351 exist for process water ponds 117 and 307 respectively. Each of these systems 350 and 351 include the aspects and preferences of process water cooling system 150. As such, for each of these ponds 117 and 307, process water is cycled through condenser 122, where it absorbs thermal energy from turbine steam, and is expelled back into the respective pond 117, 307. Thus, thermal energy from turbine steam is transferred to these ponds 117 and 307, which increases their evaporation rates. Although shown as operating in parallel with each other, process water cooling systems 350 and 351, as well as process water cooling system 150 shown in Fig. 2, may operate alone or in parallel with other cooling systems. Further, these systems may be switched as needed to permit cooling through cooling tower 124.

[65] In order to capture useful substances contained in process water ponds 117, 307, process water contained in these ponds may be transported via piping 302 and 303 respectively, and pumps 304 and 305 respectively. The piping 302, 303 and pumps 304, 305 are preferably the same types used with production facility 110 shown in Fig. 2, such as stainless steel piping used for inlet piping 154 and the vertical submersible turbine pump used for pump 152. The process water from these ponds may be used as input 140 to wet-process production method 130 as shown in Fig. 3. The increased concentration of

phosphoric acid may thereby be used to assist processing of phosphate rock 132 during production method 130, or may be captured as output from production method 130. Thus, the expense associated with treating water in these ponds 117 and 307 is avoided, and substances of value, such as phosphoric acid, are captured from these ponds.

[66] Referring now to Fig. 9, steps involved with a method 400 for capturing desirable substances from process water is shown. As shown, method 400 includes transferring 402 thermal energy from power plant 118 to process water pond 117 or 307 to increase the concentration of desirable substances. This causes the evaporation rate of pond 117, 307 to accelerate, thereby increasing the concentration of desirable substances in the process water contained therein. Method 400 further includes pumping concentrated process water from process water pond 117 or 307 to processing plant 112. At processing plant 112, method 400 includes using the concentrated process water in a production process, such as wet-process production method 130 shown in Fig. 3, to capture the desirable substances.

[67] Referring now to Fig. 10, steps involved with a method 500 for cleaning up a stagnant process water pond 117, 307 includes drawing process water from stagnant process water pond 117, 307 into an intake pipe, and pumping the process water through a heat exchanger 258 (shown in Fig. 6) or condenser 122 in thermal communication with turbine steam. Method 500 further includes pumping the process water back to process water pond 117, 307, which in effect transfers heat to the process water pond. As such,

the evaporation rate of stagnant process water pond 117, 307 is increased, which assists in cleaning up the pond.

[68] While the present invention has been described in connection with the illustrated embodiments, it will be appreciated and understood that modifications may be made without departing from the true spirit and scope of the invention. In particular, the invention applies to a wide variety of production processes, facilities and methods. Additionally, a wide variety of systems and methods may be used to transfer thermal energy from a power plant to a process water pond, to transport process water, and to make use of the process water. Further, thermal energy may be removed from a power plant at a variety of different process steps and locations. In addition, process water can constitute a wide variety of aqueous solutions containing solutes or suspended substances from manufacturing processes.